

## Review

# Brewer's *Saccharomyces* yeast biomass: characteristics and potential applications

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*Saccharomyces* yeast biomass is the second major by-product from brewing industry. It can be of value as a raw material with different uses, however, it is still underutilized, mostly, for swine and ruminant feed. This review aims to give a brief overview on applications for this agro-industrial by-product as a source of nutrients for human and fish nutrition, microbial growth, production and industrial use of brewer's yeast components and highlight the needs for further investigations and research, especially in the areas of production of ingredients for functional foods and the use of brewer's yeast as agents of detoxifying effluents containing heavy metals.

## Origin of brewer's *Saccharomyces* yeast biomass

The conventional brewing process has an extremely long history and can be regarded as a typical example of traditional biotechnology. Evidence for brewing of beer dates back to over 8000 years and since then, its pattern and consumption has changed considerably. The brewing industry

has an ancient tradition and is still a dynamic sector open to new developments in technology and scientific progress. Nowadays, beer is one of the most popular alcoholic beverages, thus, brewing industry is a huge global business. Brewer's are very concerned that the techniques they use are the best in terms of product quality and cost effectiveness.

Brewer's produce beer at an advanced technological level while keeping in mind the importance of tradition. A great many of different types, or style, of beer are brewed across the world. During production, beer alternately goes through chemical and biochemical reactions (mashing, boiling, fermentation and maturation) and three solid–liquid separations (wort separation, wort clarification and rough beer clarification) (Wunderlich & Back, 2009).

Barley (*Hordeum vulgare*) is commonly used as a source of starch but it has to be malted to dissolve starch in the grains prior to brewing. Malting steps are steeping, germination, and kilning. Enzymes digest grain contents during these processes and prepare starch for further processes (Celus, Brijs, & Delcour, 2006; Silva *et al.*, 2008). Further, enzymes convert the starch of milled malt to fermentable sugars during mashing. This procedure results in wort that is boiled. Barley malt and adjuncts (substances different from barley malt which provide additional fermentable carbohydrates) are the sources of several constituents present in beer such as, nitrogenous compounds, lipids, carbohydrates and vitamins (Bamforth 2002; Ferreira, 2009; Ferreira & Martins, 2007; Nogueira, Silva, Ferreira, & Trugo, 2005; Silva, Ferreira, & Teixeira, 2006; Silva *et al.*, 2008). Hops are added during boiling to provide bitterness and protect against bacterial spoilage, additionally, they are fundamental for good foam formation (Ferreira, Jorge, Nogueira, Silva, & Trugo, 2005).

Yeast converts sugars to alcohol during fermentation of cooled wort. Yeast has a fundamental impact on the quality of beer. It produces not only ethanol and carbon dioxide but even other compounds (higher alcohols, organic acids, esters, aldehydes, ketones, sulfur compounds) which play a key role on the sensorial profile of beer (Pinho, Ferreira, & Santos, 2006). After maturation and storage, beer is filtered and stabilized.

*Saccharomyces sensu stricto* includes *Saccharomyces bayanus*, *Saccharomyces cariocanus*, *Saccharomyces cerevisiae*, *Saccharomyces kudriavzevii*, *Saccharomyces mikatae* and *Saccharomyces paradoxus* (Kurtzman & Robnett,

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2003) are by far the yeasts most used in the brewing industry. They have several properties that make them outstanding for industrial use and especially the brewing industry, including fast growth, good ability to produce ethanol and a tolerance for several environmental stress, such as high ethanol concentration and low oxygen levels (as reviewed by Piskur & Langkjaer, 2004).

The yeasts used in breweries are conventionally divided into two main classes, bottom-fermenting and top-fermenting. Beer is also divided into two very broad categories according to which yeast is used, respectively, lager and ale. Lager yeast, known as *Saccharomyces pastorianus* or *Saccharomyces carlsbergensis*, runs the fermentation at cool temperatures (8–15 °C), and forms a cloudy mass (floculates) on the bottom of the vessel (Bamforth, 2003). The beers so produced are called bottom fermented. Lager beers produced by bottom-fermenting yeasts are the most widespread beer types throughout the world (more than 90%). To produce ale beers, strains of *S. cerevisiae* are commonly used in the temperature range of 16–25 °C.

The manufacture of beer inevitably involves generation of various residues and by-products that are being produced in large amounts annually from main beer manufacturers due to increase volume of beer production. Increasing efforts are being directed towards the reuse of agro-industrial by-products, from both economic and environmental standpoints (Fillaudeau, Blanpain-Avet, & Daufin, 2006; Musatto, 2009).

The yeast is used by the brewer several times (usually 4–6 times) and taken from one fermentation to start the next. Nevertheless, brewer's *Saccharomyces* yeast biomass is the second major by-product from brewing industry (after brewer spent grain). Its use is still limited, being basically used as animal feed. It has received little attention as a marketable commodity, and its disposal is often an environmental problem. However, it can be of value as a raw material with different uses. Several attempts have been made to use them in biotechnological processes, as for example in fermentative processes for the production of value-added compounds such as ethanol; as substrate for microorganisms cultivation, or simply raw material for extraction of compounds. This review is designed to highlight the past, present and emerging applications for this agro-industrial by-product as a source of nutrients for human and fish nutrition, microbial growth, production and industrial use of yeast components as briefly described in Fig. 1. The use of brewer's yeast as agents of detoxifying effluents is a promising potential application that was also summarized.

### Yeast culture in brewing

Until the end of the nineteenth century, yeast was not identified as the fermentation agent of wort, and beer was traditionally obtained by the action of a mixture of microorganisms, mainly represented by yeasts and bacteria, that were perpetuated from one batch to the other. E. C. Hansen

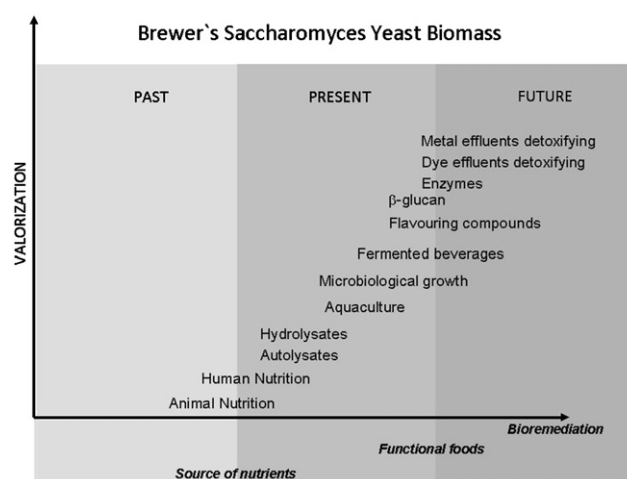


Fig. 1. Schematic representation of the Brewers Yeast Biomass valorization through the time.

from Carlsberg Brewery (Denmark) established the basis for using selected yeasts strains as starter cultures in brewing in 1883. He was the first to define ale brewing yeasts and to distinguish them from lager brewing yeasts (Rainieri, 2009). Ale yeasts are classified as *S. cerevisiae*, they differ from lager yeasts for their phenotypic and genomic characteristics. Among the major distinctive traits of these yeasts is the ability to ferment well at 20–25 °C. Lager yeasts are currently classified as *S. pastorianus*, however, their name has changed several times over the years. Hansen initially classified them as *S. carlsbergensis*, in the 1970s were referred as *Saccharomyces uvarum*. Lager stains generally cannot grow above 37 °C and ferment well at 8–10 °C.

The inoculation of wort is called “pitching” and the pitching rates depend on fermentation temperature. The pitching rates most often used are between 15 and 25 million cells/ml (Wunderlich & Back, 2009). During fermentation, yeast cell mass increases three- to six fold. The amount of yeast grown depends on the fermentation conditions of each brewery. The type of yeast as well as the condition of the pitching yeast, such as yeast generation and glycogen content, can also affect yeast growth. Low fermentation beer is produced through two fermentation steps, the primary fermentation at 8–15 °C, followed by a long secondary fermentation between −1 °C and +4 °C (the “lagering phase”). After primary fermentation 90% of the fermentable matter is consumed and most of the yeast is collected as brewer's *Saccharomyces* yeast biomass. After beer aging has been completed and the yeast, along with other insoluble material, has settled, the tank bottoms are also collected. Typically, the total amount of brewer's *Saccharomyces* yeast biomass produced in lager fermentation is about 1.7 kg/m<sup>3</sup>–2.3 kg/m<sup>3</sup> of final product (Hellborg & Piskur, 2009; Huige, 2006). Brewer's *Saccharomyces* yeast biomass usually has 10–14% total solids, including yeast solids, beer solids, and trub solids. It may retain as

much as 1.5–2.5% of the total beer production. When yeast is sold for food uses, removal of both trub solids and beer solids is generally necessary.

### Applications for brewer's *Saccharomyces* yeast biomass

World-wide spent brewer's yeast is generally sold primarily as inexpensive animal feed after inactivation by heat. Dried yeasts are an excellent source of protein for swine and ruminant, this application was reviewed recently by Huige (2006).

Commercial brewer's yeast is inactive yeast (dead yeast cells with no leaving power) remaining after the brewing process. It is an inexpensive nitrogen source with good nutritional characteristics and a very bitter taste, generally recognized as safe (GRAS). Brewer's yeast should not be confused with “brewer's type yeasts” or “nutritional yeasts”, which are pure yeasts usually grown on enriched cane or beet molasses under controlled production conditions, cultivated specifically for use as a nutritional supplement and not a by-product of the brewing process (Bekatorou, Psarianos, & Koutinas, 2006).

Interest in microorganism proteins has increased as a result of continuously growing fermentation industries which produce microorganism biomass as a by-product. A limiting factor in utilization of yeast biomass as a protein source for human consumption is its high nucleic acid content, primarily ribonucleic acid (RNA), which may account for one third of the total cell protein. Some reagents and techniques are used for isolation of yeast protein with low RNA.

Yeast biomass is not only a source of proteins but also an excellent source of B-complex vitamins, nucleic acids, vitamins and minerals, including a biologically active form of chromium known as glucose tolerance factor. Schwarz and Mertz (1959) reported that extract of brewer's yeast could reverse the impaired tolerance to glucose load in yeast fed rats. They termed the active substance in brewer's yeast tolerance factor (GTF). Toepfer, Mertz, Polanski, Rogenski, and Wolf (1977) reported that the biologically active extract from brewer's yeast contained chromium, nicotinic acid, glycine, cysteine and glutamic acid. They provided further evidence for their claim by synthesizing biologically active complexes comprised of trivalent chromium, nicotinic acid, glycine, cysteine and glutamic acid. Biologically active chromium is trivalent form, which potentiates insulin activity, measured *in vitro*. Brewer's yeast is a good source of chromium trivalent and has been studied extensively for its medicinal properties (Cefalu & Hu, 2004; Ding *et al.*, 2000). Recent studies indicate that no significant effect of chromium on lipid or glucose metabolism was found in people without diabetes. Chromium supplementation significantly improved glycemia among patients with diabetes. However, future studies that address the limitations in the current evidence are needed before definitive claims can be made about the effect of chromium

supplementation (Balk, Tatsioni, Lichtenstein, Lau, & Pittas, 2007).

Yeast biomass can be used in food industry to produce yeast protein concentrates (and isolates) while still retaining their functional properties and nutritive values. Brewer's yeast products are usually found in the form of powders, flakes or tablets, or in liquid form. Liquid yeast contains enzymatically digested yeast for better digestion, absorption and utilization. These products can be sprinkled on food, used as a seasoning or mixed with milk, juices, soups, and gravies.

Autolysis by endogenous enzymes occurs naturally in yeasts when they complete the cell growth cycle and enter the death phase. In autolysis or self-digestion, the intracellular enzymes break down proteins, glycogen, nucleic acids, and other cell constituents. The autolytic process requires careful application and control of heat to kill cells without inactivating the yeast enzymes. This process is usually carried out under moderate agitation and temperatures between 30 and 60 °C for 12–24 h. It has some disadvantages such as low extraction yield, difficulty in solid–liquid separation due to high content of residue in autolysate, poor taste characteristics as a flavour enhancer, and risk of deterioration due to microbial contamination. Plasmolysis, using inorganic salts such as sodium chloride to accelerate autolysis (Belousova, Gordienko, & Eroshin, 1995) has limited use, since there is a growing demand for processed foods containing low salt. Hydrolysis is the most efficient method of solubilizing yeast, and is carried out by hydrochloric acid or proteolytic enzymes. Despite a high production yield, acid hydrolysis is less attractive to the manufacturers because of relatively high capital investment cost, high salt content and high probability of containing carcinogenic compounds such as monochloropropanol and dichloropropanol (Huige, 2006). Autolysates and hydrolysates have several applications as a source of nutrients and bioactive compounds in aquaculture (summarized in Table 1).

### Fish nutrition

Proper nutrition has long been recognized as a critical factor in promoting normal growth and sustaining health of fish. Brewer's yeast has been recognized to have potential as a substitute for live food in the production of certain fish (Nayar, Hegde, Rao, & Sudha, 1998) or as a potential replacement for fishmeal (Oliva-Teles & Gonçalves, 2001; Rumsey, Hughes, Smith, Kinsella, & Shetty, 1991; Rumsey, Kinsella, Shetty, & Hughes, 1991). Brewer's yeast can replace 50% of fishmeal protein with no negative effects in fish performance. Moreover, the inclusion of up to 30% brewer's yeast in the diet improved feed efficiency. As a protein feedstuff, brewer's yeast has been included in commercial diet formulations for several fish species, including salmonids.

The cell wall has been suggested to cause the reduced nitrogen digestibility commonly found in single cell protein

**Table 1.** Application of autolysates and hydrolysates from brewer's yeast as a source of nutrients and bioactive compounds in aquaculture.

Brewers yeast	Fish specie used	Effects	References
Intact, disrupted and extracts from brewers dried yeast Partial replacement of fishmeal by brewers yeast, in and in isonitrogenous and isoenergetic diets	Rainbow trout ( <i>Oncorhynchus mykiss</i> ) Sea bass ( <i>Dicentrarchus labrax</i> )	Disruption of the cell wall Increases the digestibility and beneficial effects Brewers yeast can replace 50% of fishmeal protein with no negative effects 30% brewers yeast improved feed efficiency No beneficial effects were observed for supplementation of brewers yeast diets with methionine	Rumsey, Hughes et al. (1991), Rumsey, Kinsella et al. (1991) Oliva-Teles and Gonçalves (2001)
Lyophilised whole yeast	Gilthead seabream ( <i>Sparus aurata</i> L.)	Yeast supplementation improved the seabream cellular innate immune response	Ortuño et al. (2002)
Yeast <i>Saccharomyces cerevisiae</i> (0,1%)	Nile tilapia ( <i>Oreochromis niloticus</i> )	Improved growth and feed efficiency appropriate growth stimulating additive	Lara-Flores et al. (2002)
Dried brewers yeast (Brewtech®) Incremental levels 1%, 2%, 4%	Hybrid striped bass ( <i>Morone chrysops</i> × <i>M. saxatilis</i> )	Positively influenced growth performance and feed efficiency Resistance to <i>Streptococcus iniae</i> infection	Li and Gatlin (2003, 2004)
Yeast-based prebiotic mixture GroBiotic®	Hybrid striped bass ( <i>Morone chrysops</i> × <i>M. saxatilis</i> )	Immunostimulation and enhanced resistance to <i>S. iniae</i> and <i>Mycobacterium marinum</i>	Li and Gatlin (2005)
GroBiotic-A, brewer's yeast and fructooligosaccharide	Red drum ( <i>Sciaenops ocellatus</i> )	Positive effect on immune response, disease resistance and intestinal microbial community	Burr et al. (2008)
Brewer's yeast and GroBiotic®-A (each component was supplemented at 2% or 5%)	Pacific white shrimp ( <i>Litopenaeus vannamei</i> )	Dietary supplementation of GroBiotic®-A improved survival of shrimp cultured at low-salinity (2 ppt).	Li et al. (2009)
Brewers yeast commercial formulations to feed living <i>Panagrellus redivivus</i>	Fish and crustacean larvae	Low-cost technology for mass production of the free-living nematode <i>P. redivivus</i> as an alternative live food for first feeding fish and crustacean larvae	Ricci et al. (2003)

sources (Yamada & Sgarbieri, 2005). Disruption of the cell wall increases the digestibility and beneficial effects of diets containing brewer's dried yeast fed to rainbow trout (Rumsey, Hughes et al., 1991; Rumsey, Kinsella et al., 1991).

Farmfish diets should not only provide the essential nutrients that are required for normal physiological functioning but may serve as the medium by which fish receive other components that may affect their health (Gatlin, 1997, 2002; Webster, 2002). Brewer's yeast contains various immunostimulating compounds such as  $\beta$ -glucans, nucleic acids as well as mannan oligosaccharides (White, Newman, Cromwell, & Lindemann, 2002). It has been observed to be capable of enhancing immune responses (Ortuño, Cuesta, Rodríguez, Esteban, & Meseguer, 2002; Siwicki, Anderson, & Rumsey, 1994) as well as growth (Lara-Flores, Olvera-Novoa, Guzmán-Méndez, & López-Madrid, 2002) of various fish species and thus may serve as an excellent health promoter for fish culture. Brewer's yeast positively influenced growth performance and feed efficiency of hybrid striped bass as well as resistance to *Streptococcus iniae* infection. Several experiments describe the influence of dietary additives on immune response, disease resistance and intestinal microbial community (Burr, Hume, Rieke, Nisbet, & Gatlin 2008; Li et al., 2009). In addition, results of immune response assays demonstrate that brewer's yeast can be administered for

relatively long periods without causing immunosuppression (Li & Gatlin, 2003, 2004, 2005).

Additionally, brewer's yeast commercial formulations is suitable as a food source for the mass production of the nematode *Panagrellus redivivus* used for feeding farm fish and crustacean larvae (Ricci, Fifi, Ragni Schlechtriem, & Focken, 2003) during their early stages of development.

#### Microorganisms' substrate

Owing to the high level of protein, vitamin B complex and minerals, brewer's yeast cells, its autolysates and hydrolysates might be used as a nutrient source for the growth of fastidious microorganisms or related product formation. Consequently, there is an economic interest in using these yeast extracts in microbiological media and several studies were performed to evaluate growth-promoting properties of brewer's yeast extracts as summarized in Table 2. The effect of brewers' yeast extracts pure or mixed with baker's extracts were evaluated on the growth of lactobacilli and pediococci (*Lactobacillus casei* EQ28 and EQ85, *Lactobacillus acidophilus* EQ57, *Pediococcus acidilactici* MA18/5-M) to provide information for industry that formulate microbiological growth media, as well as to producers of yeast extracts. Growth of *L. acidophilus* EQ57 was best in the presence of 100% (Champagne, Gaudreau, & Conway, 2003).



**Table 2.** Application of autolysates and hydrolysates from brewer's yeast as a source of nutrients in microbiological media.

Brewers yeast	Microorganisms	Effects	Application	References
Brewers yeast extracts pure or mixed with bakers yeast	<i>Lactobacillus casei</i> EQ28 and EQ85, <i>Lactobacillus acidophilus</i> EQ57, <i>Pediococcus acidilactici</i> MA18/5-M	Only for <i>L. acidophilus</i> EQ57 growth was best in the presence 100% brewers yeast	Formulation of microbiological growth media.	Champagne et al. (2003)
Mixture of beetroot juice and autolysates of brewers yeast	<i>Lactobacillus plantarum</i> A112, <i>L. acidophilus</i> BGSJ15-3 <i>L. acidophilus</i> NCDO1748	<i>L. plantarum</i> A112 and <i>L. acidophilus</i> BGSJ15-3 can be successfully used for fermentation of the mixture of beetroot juice and brewer's yeast autolysate	Functional additive in a form of beverages, power or tablets	Rakin et al. (2004)
Mixture of beetroot juice, carrot juice and autolysates of brewers yeast	<i>L. acidophilus</i> NCDO1748	Higher mineral content in the carrot juice better improved production of lactic acid	Functional additive in a form of beverages, power or tablets	Rakin et al. (2007)
Crude yeast autolysate supplemented with minerals and vitamins	Recombinant bacterium <i>Escherichia coli</i> KO11	Increase the ethanol formation	Ethanol production	York and Ingram (1996)
Brewers yeast hydrolysate or autolysate	<i>Actinobacillus succinogenes</i> NJ113	Enzymatic hydrolysis was a more effective method due to the higher succinic acid yield and cell growth	Production of succinic acid for preparation of biodegradable polymers	Jiang et al. (2009)
Hydrothermal decomposition of proteins from brewers yeast	<i>Saccharomyces cerevisiae</i>	The growth of yeast cells in the culture medium containing 2 w/v% of this products was comparable to that of the cells grown in the medium containing commercial yeast extract at the same concentration	Hydrothermal decomposition of yeast cells for production of proteins and amino acids	Lamoolphak et al. (2006)

The importance of functional foods in the world is increasing, and the procedures for their production are under intense development. A functional food additive based on beetroot juice (*Beta vulgaris* L.) using brewer's yeast autolysate and fermented by *Lactobacillus plantarum* A112, *L. acidophilus* BGSJ15-3 and *L. acidophilus* NCDO1748 is described (Rakin, Baras, & Vukasinovic, 2004). Beetroot was chosen as a starting substance for the production of biologically highly valuable food, as there are numerous publications describing its favourable nutritive and protective benefits on humans. Fermentation using lactic acid bacteria is a widespread tradition. Brewer's yeast autolysate contributes to the increase of the number of viable cells of lactic acid bacteria during the fermentation. *L. plantarum* A112 and *L. acidophilus* BGSJ15-3 can be successfully used for this purpose.

The same authors used autolysates of brewer's yeast cells for lactic acid production by *L. acidophilus* NCDO1748 in beetroot and carrot juices enriched with brewer's yeast autolysate, in order to improve the nutritive and protective properties of the product (Rakin, Vukasinovic, Siler-Marinkovic, & Maksimovic, 2007).

Concerning the use of autolysates and for product formation, brewer's yeast autolysate has been used for ethanol production by recombinant *Escherichia coli* (York & Ingram, 1996). Spent brewer's yeast hydrolysate was evaluated as a nitrogen source for succinic acid production by

*Actinobacillus succinogenes* NJ113 in glucose-containing media to develop a cost-effective fermentation medium. Autolysis and enzymatic hydrolysis were used to hydrolyze the spent brewer's yeast cells to release the nutrients. The results showed that enzymatic hydrolysis was a more effective method due to the higher succinic acid yield and cell growth (Jiang et al., 2009).

The decomposition of proteinaceous material from brewer's yeast waste to obtain more useful products is another possibility of using this by-product. Recently, the hydrothermal decomposition into protein and amino acids of baker's yeast cells was used as a model for spent brewer's yeast waste. The reaction was carried out in a closed batch reactor at various temperatures between 100 and 250 °C. The hydrolysis product obtained at 200 °C was tested as a nutrient source for yeast growth. These results demonstrated the feasibility of using subcritical water to potentially decompose proteinaceous waste such as spent brewer's yeast while recovering more useful products (Lamoolphak, et al., 2006).

#### Food ingredients

Other possibilities of application are the production and industrial use of yeast components, such as nucleic acids, nucleotides, cell wall polysaccharides and others. The utilization of the brewer's yeast cells from beer industry for the production of food-grade yeast extract is promising, for

example, to obtain flavouring foodstuff. Flavouring enhancers, monosodium glutamic acid (MSG) and nucleotides such as 5'-guanosine monophosphate (5'-GMP) and 5'-inosine monophosphate (5'-IMP) are well known in the food processing. Yeast extract from dried brewer's yeast cells can be used by enzymatic treatment in a wide variety of foods as flavors, flavour enhancers, or flavour potentiators. Uses include meat products, sauces and gravies, soups, chips and crackers (Chae, Joo, & In, 2001; Halasz & Lásztity, 1991; Huige, 2006).

$\beta$ -Glucan obtained from brewer's yeast can be used in food products as a thickening, water-holding, or oil-binding agent and emulsifying stabilizer (Thammakiti, Supphantharika, Phaesuswan, & Verduyn, 2004). Brewer's yeast was autolysed and the cell walls were homogenized, extracted firstly with alkali, then with acid, and then spray dried. Effects of the homogenization on the chemical composition, rheological properties and functional properties of  $\beta$ -glucan were investigated. Homogenized cell walls exhibited higher  $\beta$ -glucan content and apparent viscosity than those which had not been homogenized because of fragmentation of the cell walls.

Use of prebiotics, nondigestible dietary ingredients that beneficially affect the host by selectively stimulating the growth of and/or activating the metabolism of health-promoting bacteria in the intestinal tract, is a novel concept in aquaculture. This phenomenon is worth exploring not only in human but also in fish nutrition. With the increasing concerns about use of antibiotics in aquaculture, various pre- and probiotics should receive further consideration. How to utilize dietary strategies and prebiotics to maximize the efficiency of probiotics is a promising subject and more research is warranted.

#### Future trends

The *Saccharomyces* yeast cells contain, numerous enzymes, namely, vacuolar proteases including serine, aspartyl, and metallo proteases, pectinases among others, thus, the industrial production of these enzymes from brewer's yeast is a field to explore. However, until now studies were performed only with *S. cerevisiae* ATCC 52712. The suitability of crude yeast pectinase for fruit juice extraction was reported for to aid pineapple juice extraction (Dzogbefia, Ameko, Oldham, & Ellis, 2001).

Rapid extraction of pawpaw juice with the application of locally produced pectic enzymes from *S. cerevisiae* ATCC 52712 and combined effects of enzyme dosage and reaction time on papaya juice extraction are also reported (Djokoto, Dzogbefia, & Oldham, 2006; Dzogbefia & Djokoto, 2006). The suitability of this enzyme for starch production at a local factory in Ghana was evaluated (Dzogbefia, Ofosu, & Oldham, 2008). The potential for biotechnological application of this crude enzyme preparation to pineapple and papaya juice extraction and others appears quite promising. However, for the application of the technology on an

industrial scale, parameters for the scale-up production of the enzyme will have to be carefully studied.

On the other hand, yeast cells represent an inexpensive, readily available source of biomass that has a significant potential for dye bioaccumulation. Modification of yeast cells with the perchloric acid stabilized ferrofluid lead to the formation of magnetically responsible material, which could be used as an efficient adsorbent for the removal of various water-soluble dyes (Safariková, Ptácková, Kibriková, & Safarik, 2005).

The use of inexpensive biosorbents to sequester heavy metals from aqueous solutions, is one of the most promising technologies being developed to remove these toxic contaminants from wastewaters. Considering this challenge, the viability of Cr(III) and Pb(II) removal from aqueous solutions using a flocculating yeast residual biomass from a brewing industry was studied (Ferraz, Tavares, & Teixeira, 2004). Yeast biomass showed higher selectivity and uptake capacity to lead. Still, these results were far from ideal, being necessary to make more detailed studies to reach maximum recovery.

The use of nonliving biomass of yeast *Saccharomyces* as a suitable biosorbent of metal ions (lead, zinc, copper, and nickel) is also reported. Heat-killed cells showed a higher degree of heavy metal removal than live cells, being more suitable for bioremediation works. Dead flocculent cells can be used in a low-cost technology for detoxifying metal-bearing effluents as this approach combines an efficient metal removal with the ease of cell separation (Machado, Janssens, Soares, & Soares, 2009; Machado, Santos, Gouveia, Soares, & Soares, 2008; Parvathi, Nagen-dran, & Nareshkumar, 2007; Zouboulis, Matis, & Lazaridis, 2001). The application of *S. cerevisiae* as a biosorbent not only removes metals from wastewaters but also eases the burden of disposal costs associated with the waste. However, literature on the application of biosorption to "real" industrial effluents is still scarce.

#### References

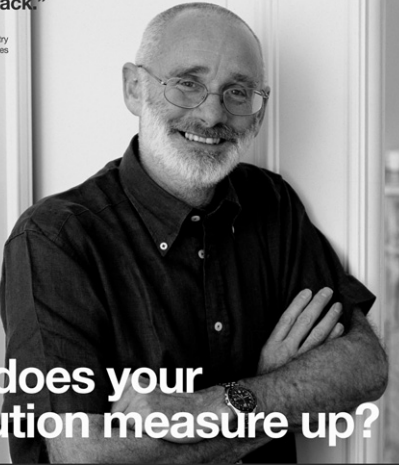
- Balk, E. M., Tatsioni, A., Lichtenstein, A. H., Lau, J., & Pittas, A. G. (2007). Effect of chromium supplementation on glucose metabolism and lipids. A systematic review of randomized controlled trials. *Diabetes Care*, 30, 2154–2163.
- Bamforth, C. (2003). Yest and fermentation. *Beer: Tap into the art and science of brewing*. New York: Oxford University Press, pp. 144–159.
- Bamforth, C. W. (2002). Nutritional aspects of beer – a review. *Nutrition Research*, 22, 227–237.
- Bekatorou, A., Psarianos, C., & Koutinas, A. (2006). Production of food grade yeasts. *Food Technology and Biotechnology*, 44(3), 407–415.
- Belousova, N. I., Gordienko, S. V., & Eroshin, V. K. (1995). Influence of autolysis conditions on the properties of amino-acid mixtures produced by ethanol-assimilating yeast. *Applied Biochemistry Microbiology*, 31, 391–395.
- Burr, G., Hume, M., Ricke, S., Nisbet, D., & Gatlin III, D. M. (2008). A preliminary in vitro assessment of GroBiotic-A, brewer's yeast and fructooligosaccharide as prebiotics for the red drum *Sciaenops ocellatus*. *Journal of Environmental Science and Health B*, 43, 253–260.

- Cefalu, W. T., & Hu, F. B. (2004). Role of chromium in human health and in diabetes. *Diabetes Care*, 27(11), 2741–2751.
- Celus, I., Brijs, K., & Delcour, J. A. (2006). The effects of malting and mashing on barley protein extractability. *Journal of Cereal Science*, 44, 203–211.
- Chae, H. J., Joo, H., & In, M. J. (2001). Utilization of brewer's yeast cells for the production of food-grade yeast extract. Part 1: effects of different enzymatic treatments on solid and protein recovery and flavor characteristics. *Bioresource Technology*, 76(3), 253–258.
- Champagne, C. P., Gaudreau, H., & Conway, J. (2003). Effect of the production or use of mixtures of brewers' yeast extracts on their ability to promote growth of lactobacilli and pediococci. *Electronic Journal of Biotechnology*, ISSN: 0717-3458.
- Ding, W. J., Qian, Q. F., Hou, X. L., Feng, W. Y., & Chai, Z. F. (2000). Determination of chromium combined with DNA, RNA and proteins in chromium-rich brewer's yeast by NAA. *Journal of Radioanalytical and Nuclear Chemistry*, 244(2), 259–262.
- Djokoto, D., Dzogbefia, V. P., & Oldham, J. H. (2006). Rapid extraction of pawpaw juice with the application of locally produced pectic enzymes from *Saccharomyces cerevisiae* ATCC 52712. *Food Biotechnology*, 20, 31–41.
- Dzogbefia, V. P., Ameko, E., Oldham, J. H., & Ellis, W. O. (2001). Production and use of yeast pectolytic enzymes to aid pineapple juice extraction. *Food Biotechnology*, 15(1), 25–34.
- Dzogbefia, V. P., & Djokoto, D. K. (2006). Combined effects of enzyme dosage and reaction time on papaya juice extraction with the aid of pectic enzymes – a preliminary report. *Journal of Food Biotechnology*, 30(1), 117–122.
- Dzogbefia, V. P., Ofosu, G. A., & Oldham, J. H. (2008). Evaluation of locally produced *Saccharomyces cerevisiae* pectinase enzyme for industrial extraction of starch from cassava in Ghana. *Scientific Research and Essay*, 3(8), 365–369.
- Ferraz, A. I., Tavares, T., & Teixeira, J. A. (2004). Cr(III) removal and recovery from *Saccharomyces cerevisiae*. *Chemical Engineering Journal*, 105, 11–20.
- Ferreira, I. M. P. L. V. O. (2009). Beer carbohydrates. In V. R. Preedy (Ed.), *Beer in health and disease prevention* (pp. 290–298). New York: Elsevier.
- Ferreira, I. M. P. L. V. O., Jorge, K., Nogueira, L. C., Silva, F., & Trugo, L. C. (2005). Effects of the combination of hydrophobic polypeptides, iso-alpha acids, and malto-oligosaccharides on beer foam stability. *Journal of Agricultural and Food Chemistry*, 53, 4976–4981.
- Ferreira, I. M. P. L. V. O., & Martins, F. (2007). Carbohydrate content of lager and ale beers. *Alimentação Humana*, 13, 26–31.
- Fillaudeau, L., Blanpain-Avet, P., & Daufin, G. (2006). Water, wastewater and waste management in brewing industries. *Journal of Cleaner Production*, 14, 463–471.
- Gatlin III, D. M. (1997). Nutrition and feeding of striped bass and hybrid striped bass. In R. M. Harrell (Ed.), *Striped bass and other Morone culture* (pp. 235–251). Amsterdam: Elsevier.
- Gatlin III, D. M. (2002). Nutrition and fish health. In J. E. Halver, & R. W. Hardy (Eds.), *Fish nutrition* (pp. 671–702). San Diego: Academic Press.
- Halasz, A., & Lásztity, R. (1991). *Use of yeast biomass in food production*. New York: Academic Press.
- Hellborg, L., & Piskur, J. (2009). Yeast diversity in the brewing industry. In V. R. Preedy (Ed.), *Beer in health and disease prevention* (pp. 1068–1073). New York: Elsevier.
- Huige, N. J. (2006). Brewery by-products and effluents. In F. G. Priest, & G. G. Stewart (Eds.), *Handbook of brewing* (pp. 656–713). Boca Raton: CRC Press.
- Jiang, M., Chen, K., Liu, Z., Wei, P., Ying, H., & Chang, H. (2009). Succinic acid production by *Actinobacillus succinogenes*: using spent brewer's yeast hydrolysate as a nitrogen source. *Biotechnology and Applied Biochemistry*, doi:10.1007/s12010-009-8649-1. Accessed May 2009.
- Kurtzman, C. P., & Robnett, C. J. (2003). Phylogenetic relationships among yeasts of the 'Saccharomyces complex' determined from multigene sequence analyses. *FEMS Yeast Research*, 3, 417–432.
- Lamoolphak, W., Goto, M., Sasaki, M., Suphantharika, M., Muangnapoha, C., Prommuag, C., et al. (2006). Hydrothermal decomposition of yeast cells for production of proteins and amino acids. *Journal of Hazardous Materials B*, 137, 1643–1648.
- Lara-Flores, M., Olvera-Novoa, M. A., Guzmán-Méndez, B. E., & López-Madrid, W. (2002). Use of the bacteria *Streptococcus faecium* and *Lactobacillus acidophilus*, and the yeast *Saccharomyces cerevisiae* as growth promoters in Nile tilapia (*Oreochromis niloticus*). *Aquaculture*, 216, 193–201.
- Li, P., & Gatlin III, D. M. (2003). Evaluation of brewer's yeast (*Saccharomyces cerevisiae*) as a feed supplement for hybrid striped bass (*Morone chrysops* × *M. saxatilis*). *Aquaculture*, 219, 681–692.
- Li, P., & Gatlin III, D. M. (2004). Dietary brewer's yeast and the prebiotic GroBiotic AE influence growth performance, immune responses and resistance of hybrid striped bass (*Morone chrysops* × *M. saxatilis*) to *Streptococcus iniae* infection. *Aquaculture*, 231, 445–456.
- Li, P., & Gatlin III, D. M. (2005). Evaluation of the prebiotic GroBioticR-A and brewers yeast as dietary supplements for sub-adult hybrid striped bass (*Morone chrysops* × *M. saxatilis*) challenged in situ with *Mycobacterium marinum*. *Aquaculture*, 248, 197–205.
- Li, P., Wang, X., Murthy, S., Gatlin III, D. M., Castille, F. L., & Lawrence, A. L. (2009). Effect of dietary supplementation of brewer's yeast and GroBiotic®-A on growth, immune responses, and low-salinity tolerance of pacific white shrimp *Litopenaeus vannamei* cultured in recirculating systems. *Journal of Applied Aquaculture*, 21, 110–119.
- Machado, M. D., Janssens, S., Soares, H. M., & Soares, E. V. (2009). Removal of heavy metals using a brewer's yeast strain of *Saccharomyces cerevisiae*: advantages of using dead biomass. *Journal of Applied Microbiology*, 106, 1792–1804.
- Machado, M. D., Santos, M. S. F., Gouveia, C., Soares, H. M. V. M., & Soares, E. V. (2008). Removal of heavy metals using a brewer's yeast strain of *Saccharomyces cerevisiae*: the flocculation as a separation process. *Bioresource Technology*, 99, 2107–2115.
- Mussatto, S. I. (2009). Biotechnological potential of brewing industry by-products. *Biotechnology for agro-industrial residues utilisation*. Netherlands: Springer. pp 313–326.
- Nayar, S., Hegde, S., Rao, P. S., & Sudha, P. (1998). Live organisms as feed in aquaculture. *Infofish International*, 4, 36–39.
- Nogueira, L. C., Silva, F., Ferreira, I. M. P. L. V. O., & Trugo, L. C. (2005). Separation and quantification of beer carbohydrates by high-performance liquid chromatography with evaporative light scattering detection. *Journal of Chromatography A*, 1065(2), 207–210.
- Oliva-Teles, A., & Gonçalves, P. (2001). Partial replacement of fishmeal by brewers yeast (*Saccharomyces cerevisiae*) in diets for sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture*, 202, 269–278.
- Ortuno, J., Cuesta, A., Rodríguez, A., Esteban, M. A., & Meseguer, J. (2002). Oral administration of yeast, *Saccharomyces cerevisiae*, enhances the cellular innate immune response of gilthead seabream (*Sparus aurata* L.). *Veterinary Immunology and Immunopathology*, 85, 41–50.
- Parvathi, K., Nagendran, R., & Nareshkumar, L. R. (2007). Lead bio-sorption onto waste beer yeast by-product: a means to decontaminate effluent generated from battery manufacturing industry. *Journal of Biotechnology*, 10(1), 92–105.
- Pinho, O., Ferreira, I. M. P. L. V. O., & Santos, L. H. M. L. M. (2006). Method optimization by solid-phase microextraction in combination with gas chromatography with mass spectrometry for analysis of beer volatile fraction. *Journal of Chromatography A*, 1121, 145–153.
- Piskur, J., & Langkjaer, R. B. (2004). Yeast genome sequencing: the power of comparative genomics. *Molecular Microbiology*, 53, 381–389.

- Rainieri, S. (2009). The brewer's yeast genome: from its origins to our current knowledge. In V. R. Preedy (Ed.), *Beer in health and disease prevention* (pp. 89–101). New York: Elsevier.
- Rakin, M., Baras, J., & Vukasinovic, M. (2004). The influence of brewer's yeast autolysate and lactic acid bacteria on the production of a functional food additive based on beetroot juice fermentation. *Food Technology and Biotechnology*, 42(2), 109–113.
- Rakin, M., Vukasinovic, M., Siler-Marinkovic, S., & Maksimovic, M. (2007). Contribution of lactic acid fermentation to improved nutritive quality vegetable juices enriched with brewer's yeast autolysate. *Food Chemistry*, 100, 599–602.
- Ricci, M., Fifi, A. P., Ragni, A., Schlechtriem, C., & Focken, U. (2003). Development of a low-cost technology for mass production of the free-living nematode *Panagrellus redivivus* as an alternative live food for first feeding fish larvae. *Applied Microbiology and Biotechnology*, 60, 556–559.
- Rumsey, G. L., Hughes, S. G., Smith, R. R., Kinsella, J. E., & Shetty, K. J. (1991). Digestibility and energy values of intact, disrupted and extracts from dried yeast fed to rainbow trout (*Oncorhynchus mykiss*). *Animal Feed Science and Technology*, 33, 185–193.
- Rumsey, G. L., Kinsella, J. E., Shetty, K. J., & Hughes, S. G. (1991). Effect of high dietary concentrations of brewer's dried yeast on growth performance and liver uricase in rainbow trout (*Oncorhynchus mykiss*). *Animal Feed Science and Technology*, 33, 177–183.
- Safariková, M., Ptácková, L., Kibriková, I., & Safarik, I. (2005). Biosorption of water-soluble dyes on magnetically modified *Saccharomyces cerevisiae* subsp. *uvarum* cells. *Chemosphere*, 59, 831–835.
- Schwarz, K., & Mertz, W. (1959). Chromium (III) and the glucose tolerance factor. *Archives of Biochemistry and Biophysics*, 85, 292–295.
- Silva, F., Ferreira, I. M. P. L. V. O., & Teixeira, N. (2006). Polypeptides and proteins with influence on beer foam quality and analytical methods used in its study. *Química Nova*, 29(6), 1326–1331.
- Silva, F., Nogueira, L. C., Gonçalves, C., Ferreira, A. A., Ferreira, I. M. P. L. V. O., & Teixeira, N. (2008). Electrophoretic and HPLC methods for comparative study of the protein fractions of malts, worts and beers produced from Scarlett and Prestige barley (*Hordeum vulgare* L.) varieties. *Food Chemistry*, 106, 820–829.
- Siwicki, A. K., Anderson, D. P., & Rumsey, G. L. (1994). Dietary intake of immunostimulants by rainbow trout affects non-specific immunity and protection against furunculosis. *Veterinary Immunology and Immunopathology*, 41, 125–139.
- Thammakitti, S., Supphantharika, M., Phaesuwan, T., & Verduyn, C. (2004). Preparation of spent brewer's yeast [beta]-glucans for potential applications in the food industry. *International Journal of Food Science & Technology*, 39(1), 21–29.
- Toepfer, E. W., Mertz, W., Polanski, N. M., Rogenski, E. E., & Wolf, W. R. (1977). Preparation of chromium containing material of glucose tolerance factor activity from brewers yeast and synthesis. *Journal of Agricultural and Food Chemistry*, 25, 162–165.
- Webster, C. D. (2002). Hybrid striped bass. In C. D. Webster, & C. Lim (Eds.), *Nutrient requirements and feeding of finfish for aquaculture* (pp. 327–343). Wallingford: CABI Publishing.
- White, L. A., Newman, M. C., Cromwell, G. L., & Lindemann, M. D. (2002). Brewers dried yeast as a source of mannan oligosaccharides for weanling pigs. *Journal of Animal Science*, 80, 2619–2628.
- Wunderlich, S., & Back, W. (2009). Overview of manufacturing beer: ingredients, processes, and quality criteria. In V. R. Preedy (Ed.), *Beer in health and disease prevention* (pp. 3–16). New York: Elsevier.
- Yamada, E., & Sgarbieri, A. V. C. (2005). Yeast (*Saccharomyces cerevisiae*) protein concentrate: preparation, chemical composition, and nutritional and functional properties. *Journal of Agricultural and Food Chemistry*, 53, 3931–3936.
- York, S. W., & Ingram, L. O. (1996). Ethanol production by recombinant *Escherichia coli* KO11 using crude yeast autolysate as a nutrient supplement. *Biotechnology Letters*, 18, 683–688.
- Zouboulis, A. I., Matis, K. A., & Lazaridis, N. K. (2001). Removal of metal ions from simulated wastewater by *Saccharomyces* yeast biomass: combining biosorption and flotation processes. *Separation Science and Technology*, 36(3), 349–365.

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